Using an Einstein's idea to explain OPERA faster than light neutrinos.

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The OPERA experiment has reported 16000 neutrinos obtained from 10500ns LHC proton beams plus 20 neutrinos from short 3ns LHC beams, that apparently arrive to Gran Sasso Laboratory $\sim 60ns$ earlier that expected for light. This puzzling result could be partially explained, at least for long LHC beams, by stimulated absorption of neutrinos in the decay tunnel in close analogy with a pulse LASER.

I. INTRODUCTION

An surprising announcement by OPERA team [1], reporting velocities faster than light for neutrinos detected at Gran Sasso Laboratory, coming from the CERN at 730 km away, has recently captured worldwide attention. What is most amazing is that the velocity obtained is even faster than the known speed of light in the vacuum, within margins of error accurately calculated. This result is in direct contradiction with Einstein's Relativity Theory that has been the angular corner of modern physics for more than a century. The speed of light in vacuum is considered to be the limit velocity for all matter and information travel, as a consequence of the causality principle.

Theoretical physics usually deals with "tachyons" or particles faster than light, but these are regarded as "non physical states" or ghost" or "failures" of a theory that must be corrected in order to eliminate tachyonic states. Some exotic theories allow them, in a non interacting non causal violating way [2]. But neutrino is a Standard Model matter particle, so it must have positive mass and will not be allowed to travel faster than the speed of light without severe effects on almost all our current physical understanding of nature.

Then, could the XXI century physics finish with the reign of Relativity?. Most physicists believe that this is not the case. There are 90 years of experimental results, starting from the Eddington's experiment till present satellite observations supporting Einstein Relativity. Probably the stronger result against neutrinos faster than light, comes from the observations of the SuperNova 1987A [3]. In 1987 three independent neutrino observatories: *Kamiokande II* in Japan, *IMB* in USA, and *Baksan* in the former USSR detected 11, 8 and 5 neutrino events, in a burst lasting less than 13s almost at the same UTC time. Approximately three hours later the light from the Nova was observed, there was another detection of 5 neutrinos in *Mont Blanc* (not necessarily correlated) almost at the same time of the sight of the Nova. This does not indicate that neutrinos arrived faster than light, the accepted explanation is that neutrinos arise from the collapse of the star core, but the burst of light occurs only when the shock waves reach the star surface. If OPERA result is right, the neutrinos must precede the light by 60ns for each 730km, as Nova 1987A is 168.000 light year away from the earth, neutrinos must arrived earth 1500 days BEFORE the explosion was observed, an not few hours earlier.

So, how the announcement by OPERA collaboration, using a billion dollar accelerator and two 625 Tons detector by 174 prestigious scientists is to be explained?. Is this a terrible mistake or there is some new physics underlying?.

II. THE EXPERIMENT

First of all it is necessary to outline the experiment. The proton beam is produced with the CERN Super Proton Synchrotron (SPS), these protons are ejected with a kicker magnet, in two extractions each lasting 10.5μs and separated by 50ms towards a graphite target where billions of mesons are produced. These mesons are focused into a 1km vacuum tunnel where the mesons decays into muons and neutrinos. Then neutrinos continue traveling through the inside of the earth by 730km until they arrive to Gran Sasso Laboratory 2.4ms later. Neutrinos are detected by OPERA in two separated groups: the first with mean neutrino energy of $13,9GeV$ and the second with $42,9GeV$, corresponding to each one of the two proton extractions.

Proton extractions are similar to step functions with several peak or oscillations superposed. These peaks corresponds to the proton synchrotron radio frequencies of the SPS and the kicker magnet. The form of the time distribution of proton function is accurately measured by a fast Beam Current Transformer (BCT) at center of the graphite target. The key of the experiment is that each maximum of the neutrinos detection must correspond to a maximum of the proton intensity.

To obtain the time traveling of the neutrinos, each of $\sim$ 16000 neutrino events detected were tag in time, and correlated with its corresponding proton time distribution function for each extraction with high accuracy. To do that, a probability density function (PDF) is constructed, summing up all the proton time distribution function, for which neutrino interactions were observed at the detector. Then this function is shifted in time ($t \to t+TOF_c$) by the

estimated time of flight ($TOF_c = \frac{730.085km}{c}$) at the speed of light c. The peaks of these PDF function must correspond in time with the peaks in the neutrino detection if they fly exactly at the speed of light. The measured neutrino time distribution, detected at OPERA must have a delay time ($t \rightarrow t + TOF_\nu$), corresponding to the time of flight of the neutrinos ($TOF_\nu = \frac{730.085km}{v}$) at its real velocity v. As both time functions, the theoretical PDF function and the detected neutrinos distribution had been shifted by TOF_c and TOF_ν respectively; the maximum likehood analysis must gives the best fitting for a time lapse [1]:

$$\delta t = TOF_c - TOF_\nu$$

If this time lapse is positive means that the neutrinos arrived faster than expected for light, while if this quantity is negative means that the neutrinos are slower than light.

To obtain the average delay in time, between the neutrino detection and the PDF function, a numerical maximum likehood analysis is performed. The results are shown separately for each of the the two extraction, that are enough separated by $50ms$ to be uncorrelated. The results are summarized in figure 1 [1]:

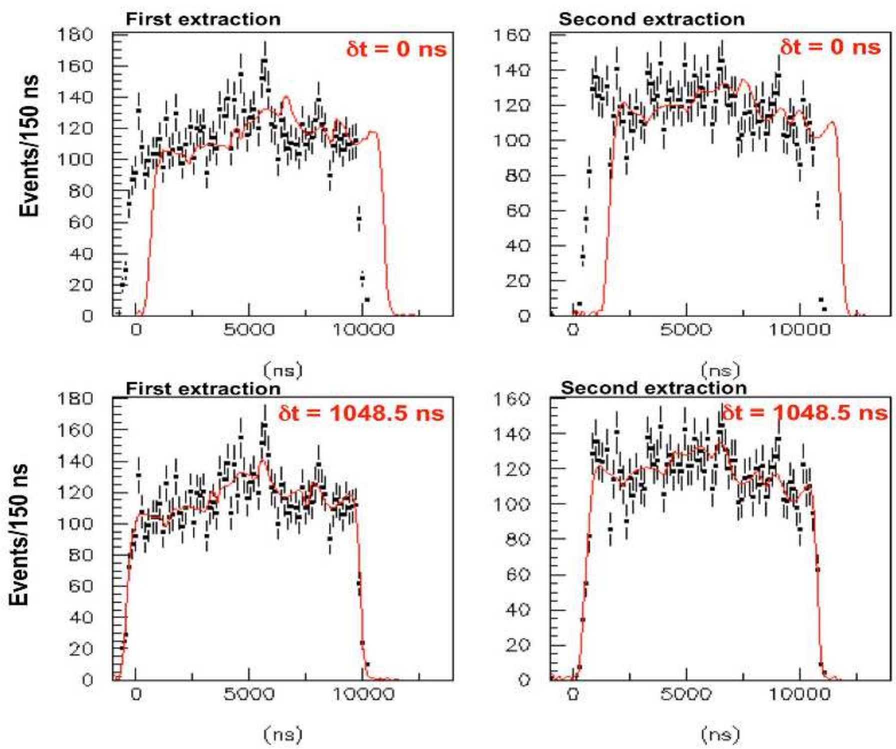

FIG. 1: Graphic of results of the PDF for mesons and the detected neutrinos detected by OPERA

Surprisingly, a positive lapse shift of $\delta t = 1048.5ns$ was obtained, indicating an early arrive than expected at the speed of light, there are corrections due to the electronic time tag GPS, UTC, BCT, etc that are summed up to $(985.8 \pm 7.4)ns$, when all the chain of systemic errors is taken into account. So, there is still an unexplained forward lapse of:

$$(57.8 \pm 7.8 \pm^{8.3}_{5.9})ns$$

that indicates that neutrinos are 0.25×10^{-4} faster than known speed of light in the vacuum. In this result had been included the statistical error $\pm 6.9ns$ obtained from the maximum likehood analysis, and checked with various combination of MonteCarlo simulations.

Recently the OPERA collaboration has reported 20 neutrino events obtained for very short proton extraction pulse, with a gaussian PDF mean width of only $3ms$, that is roughly one thousand times shorter than $10.5\mu s$ former events,

that also appears to precede light for

$$62.1ns \qquad RMS := 16.4ns$$

This result of only 20 events has a very high Root Mean Square of $RMS := 16.4ns$, so it will be significant only when taken jointly with the previous 16000 events result.

III. DISCUSSION.

So, how is to be interpreted this result?. It has been argued in that the statistical error has been underestimated and really is bigger, so the result is an statistical effect [4]. The maximum likehood analysis performed is very elaborated, and Montecarlo calculations override this objections, because it a generates an ensemble of possibilities from which the statistical errors could be accurately computed. Another explanation was presented on the basis of interaction of neutrinos with modified gravities [5] or some kind of dark matter or monopoles [7][6]. These interaction could produce radiative corrections in the vacuum polarization that produces group velocity larger than the speed of light. But if the time distribution of neutrinos (or the PDF) is to be thought as the envelope of a wave traveling wave packages, then the individuals peaks or local maximum must correspond with a particular neutrino (at least with the detected event closer to each peak)so these neutrinos must be traveling at the group velocity, so again faster than light neutrinos are recovered.

So, how to interpret the OPERA result?. Could be that muonic neutrinos are indeed faster than light, while electronic neutrinos are in fact closer, but slower, to the speed of light as indicated Nova 1987A observation?. Could be possible that neutrinos are taking shortcuts [8] in extra dimensions or non Einstein like spaces?.

IV. A PROPOSAL

It is not know in which part of the $1000m$ tunnel the decay of mesons into neutrino plus muon occurs, the statistical correlation of thousands of neutrino peak distribution against the PDF function will give the mean delay time with high statistical precision when it is assumed that the spatial distribution of the decays in the tunnel is random or gaussian, but it could happens that the starting point of neutrinos could be shifted in time or driven by stimulated emission-absorption, as happens for a pulse LASER traveling through an amplifier plasma with an initial population [9].

If we accept that a process of stimulated emission-absorption occurs in the tunnel, it will happens that when the mesons travels through the tunnel and these processes deform the wave packet. So, although at the entry, mesons have the same time distribution as their protons parents (that is similar to an step function with several peaks superposed), outgoing muons and neutrinos could have differences with respect to their mesons parents. When the mesons of the first peak decays into the tunnel, it is expected that the velocity of the created muons will be a less than that of the incoming meson. This is due to energy conservation because neutrino mass is very small while meson and muon mass are similar. So the next incoming meson will reach the muons, that are still correlated with its neutrino, because the wave function of the neutrino is extremely large (if its mass is enough small), so these increments in population density "stimulates" farther mesons to decay with the emisión of a neutrino or "induces" farther muons to absorb the neutrino. So, semi-classically speaking, the neutrinos coming from the decay of mesons from later peaks will start its journey from CERN to OPERA with an forward spatial shift with respect to their parent mesons. If the traveling distance of the stimulated neutrinos is shorter than that of the not stimulated ones this will explain the OPERA faster than light neutrinos, they are traveling a shortening distance.

It may sounds weird to talk about "stimulated emission" (or stimulated absorption) of neutrinos, process usually related to bosons. But the decaying process in the tunnel could be looked BACKWARD in time as an emission of mesons (that is a boson) that occurs when a neutrino (that takes the role of a electron) decays from an "excited or ionized" state into a "lower or ground" bounded state with the muon (that takes the role of the atom). As could be seen in Fig 2b.

In the forward of time look, see Fig 2a, there is an incoming boson (the meson) that is absorbed by the atom (the neutrino in bounded state with the muon) and then the neutrino (the electron in the analogy) jump to an excited state. This excited state is an ionized state that is in the continuous part of the spectra. So this is analog to the photoelectric effect. So there is no restrictions to a boson, that is the meson, to undergoes "stimulated absorption" by the media (muon-neutrino instead of atoms) that "ionizes" a neutrino to the continuous levels.

The energy balance equation could be written, in a similar way to the Einstein's famous paper by in 1917 [10] with a slight modification. As we are interested primary in neutrino production, is better to consider the process as a

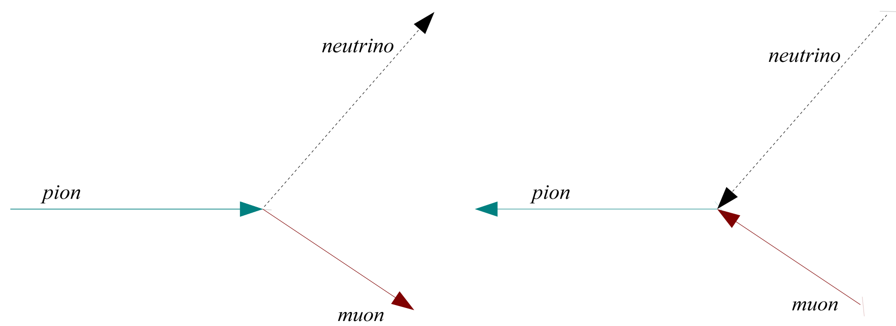

FIG. 2: a. Forward in time absorption of a meson (left); b. Backward in time emission of a meson(right)

forward in time stimulated emission (absorption) of neutrinos, rather than a backward in time stimulated absorption (emission) of bosons. There's will be no conflict with the Pauli exclusion principle, because the neutrinos goes to the continuous spectra of this "atoms" and not the the same level.

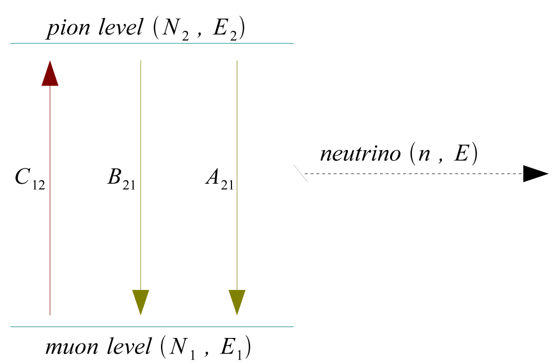

FIG. 3: Two levels decay emission, stimulated emission and absorption

Lets us consider the simple two level system of Fig 3. The balance equation or Laser equations could be written as:

$$\frac{\partial n}{\partial t} + \frac{\partial n}{\partial x}.\nu = N_2\ A_{21} + N_2\ B_{21}\ n - N_1\ C_{12}\ n \tag{1}$$

$$\frac{\partial n}{\partial t} + \frac{\partial n}{\partial x}.\nu = -\frac{\partial N_2}{\partial t} - \frac{\partial N_2}{\partial x}.v_\pi \tag{2}$$

$$\frac{\partial n}{\partial t} + \frac{\partial n}{\partial x}.\nu = \frac{\partial N_1}{\partial t} + \frac{\partial N_1}{\partial x}.v_\mu \tag{3}$$

Here E_1 is the muon energy or ground state, with a density of particles N_1. The meson energy is E_2 for the excited states and has density number N_2. The neutrino energy is then $E = E_2 - E_1$, with neutrino density number n. The neutrino velocity is ν, and the the meson and muon velocities are ν_π and ν_μ respectively. All those densities will be functions of the tunnel length x and the time t. Finally $A_{21},\ B_{21},\ C_{12}$ are the Einstein's coefficients, respectively the spontaneous emission coefficient, the stimulated or induced emission coefficient and the last one the absorption coefficient.

So the first term, at left hand of Eq.(1) is the total creation or destructions of neutrinos taking into accounts those that enter, exit, appears or vanishes in the decay tunnel. At the right hand of Eq.(1), the term proportional to A_{21} is the natural or spontaneous emission, the term proportional to B_{21} is the stimulated emission, while the last term,

proportional to C_{12} is the absorption of neutrinos by muons to create mesons. Note that the last two terms depends on both pion and neutrino densities or muon and neutrino density, so they are quadratical in the densities while the first term is only linear.

The equation (2) is a conservation equation that indicates that the "source" of neutrino is just the "sink" of mesons. Equation (3) indicates that, also the "source" of muons is the "sink" of mesons. Note that (3) do indicates that the density of muons "inside" the tunnel is not exactly the number of neutrinos, because muons travel a little slower than neutrinos $v_\mu < \nu$ so they remain a little longer time in the tunnel and its density depends also on the velocities.

This set of equations reduces to the standard balance equation for Laser [9] in several cases. For example if we take the stationary case, for which all time derivatives are null, taking $A_{21} \approx 0$, for simplicity, when the gradient of both mesons density N_1 and muon densities N_2 small, we get:

$$n(x) = n_o \; e^{\; c/\nu (N_2 B_{21} - N_1 C_{12}) \; x} \tag{4}$$

.

When $N_2 B_{21} > N_1 C_{12}$, there is an "population inversion" and the numbers of neutrinos increase exponentially, that is what happens in a Laser. But when $N_2 B_{21} < N_1 C_{12}$ there is the usual Beer-Lambert absorption law.

Never before there has been observed a so high flux of mesons, muons and neutrinos as those coming from the CERN, therefore it may be the first time that a this stimulated processes has been achieved on earth. So, a careful analysis of the OPERA experiment result must be perform in order to establishes the existence or not of the stimulated neutrino production or absorption, and of course to establishes, is these could explain the reported neutrinos faster than light.

For both stimulated emission and/or absorption of neutrinos Einstein coefficients are expected to be very small. So, they will only matters when both N_2 and n and/or N_1 and n are large enough, For simplicity lets assume $A_{21} \approx 0$, introducing characteristic coordinates ($c = 1$) then we get from the Eq. (1):

$$\frac{\partial n}{\partial \eta} = (N_2 \; B_{21} - N_1 C_{21}) \; n \qquad \text{where} \qquad \eta = t + \frac{x}{\nu}, \; \xi = t - \frac{x}{\nu} \tag{5}$$

that could be integrated when the gradient of both mesons and muons densities are almost constants

$$n(\eta) = n_o \; e^{\; (N_2 B_{21} - N_1 C_{12}) \; \eta} \tag{6}$$

For pulses of light traveling through an transparent not absorbing media, it is known [9] that the wave equation for a pulse, with a gaussian distribution of frequencies centered at ω_o and with root mean squared RMS proportional to the duration of the pulse: $\sqrt{\Gamma} = \sigma \propto T$. For such pulses, the wave function in configuration space is:

$$\varepsilon(x,t) = \sqrt{\frac{\Gamma(x)}{2\pi}} \exp[i\omega_o(t - \frac{x}{v_\phi})] \exp[-\frac{\|\Gamma\| \, (x)}{2}(t - \frac{x}{v_g})^2], \tag{7}$$

where $k = \frac{N(\omega)}{c}$ is a frequency dependent spatial wave number, and with the refraction index $N = N(\omega)$ also frequency dependent.

Eq.(7) is similar to "plane waves" with phase velocity propagating factor

$$v_\phi = \left(\frac{\omega}{k}\right)_{\omega_o} = \frac{c}{N(\omega)}, \tag{8}$$

that, because the probability density depends on the squared norm of (7), it is not physically observable. These "plane waves" are also modulated by a gaussian factor, whose center travels along the characteristic ξ (so each constant ξ defines a wave front) with group velocity given by

$$v_g = \left(\frac{d\omega}{dk}\right)_{\omega_o} = c\left(N(\omega) + \omega \; \frac{dN(\omega)}{d\omega}\right)^{-1} \tag{9}$$

It is well known that wave Eq.(7) suffers spreading or broadening and height shortening [11] while propagating due to the "group velocity dispersion"

$$\Gamma(x) = \left(\frac{1}{\Gamma} + 2ik''(\omega)\ x\right)^{-1} \tag{10}$$

produced by the deforming shape factor $\Gamma(x)$ that is different for each frequency when k'' is not zero.

What is not so well known, is that when a pulse travels through an amplifier media (as described above) it undergoes a deformation that could be described as multiplying (7) by the amplifying factor that is obtained taking squared root in Eq.(4). Then, if we take the neutrino pulses to be given by Eq.(7) at the beginning of the tunnel, with group velocity equals neutrino speed ($c_\nu = v_g$), the neutrino wave function inside the decay tunnel, could be written as:

$$\varepsilon_\nu = \sqrt{\frac{\Gamma_o n_o}{4\pi}} \exp[i\omega_o(t - \frac{x}{v_\phi})] \exp[-\frac{\Gamma_o}{4}(\xi)^2] e^{\ (N_2 B_{21} - N_1 C_{12})\ \eta/2} \tag{11}$$

where we have replace $\Gamma(x)$ by Γ_o that is the inverse of the the mean time squared of the neutrinos pulses, and we take $k''(\omega) = 0$, because radiative corrections to the refraction index N must be very small, so here will be not dark matter, ether, or anomalous gravity interactions, note the factor $\eta/2$ in the exponential, when $\xi = 0$ we get $x = ct$ then $\eta = 2x/c$ so the gain factor for wave function squared Eq. (11) will be the same for intensity Eq. (4).

This equation represent a pulse of neutrinos, with exponential gain while moving along characteristic η, and with gaussian spreading in the other characteristic ξ. Note that the characteristics will be orthogonal if $v = c$.

Neutrino density is given by the squared norm of Eq. (11), so the phase velocity does not takes part in this process:

$$n \propto \exp[-\frac{\Gamma_o}{2}(\xi)^2] e^{\ (N_2 B_{21} - N_1 C_{12})\ \eta} \tag{12}$$

if stimulated processes does not exist ($B_{21} = C_{21} = 0$), a wave packet centered at the entry of the tunnel at the initial time ($x = 0, t = 0$) will preserve its shape after traveling by the tunnel, and the maximum (peaks) must reach the end of the tunnel $x = L$, at time $t_1 = L/c$. But if $B_{21} \neq 0$ and $C_{12} \neq 0$ the intensity will have a deformed shape and its maximum must reach tunnel's end $x = L$, at time t_2

$$\left(\frac{\partial n}{\partial t}\right)_{(x=L,t=t_2)} = 0 \Longrightarrow -\Gamma_o(t_2 - \frac{L}{c}) + (N_2 B_{21} - N_1 C_{12}) = 0 \tag{13}$$

$$t_2 = t_1 + \frac{(N_2 B_{21} - N_1 C_{12})}{\Gamma_o} \Longrightarrow \Delta t = \frac{(N_2 B_{21} - N_1 C_{12})}{\Gamma_o} \tag{14}$$

Finally, the conclusion is that at the end of the tunnel $x = L$, the outgoing neutrino pulse will have an apparent forward in time lapse shift, with respect to the time of flight of the light $t_1 = L/c$ when Δt is negative That is when the neutrinos wave function maximum arrives earlier: $t_2 < t_1$. This will happens when stimulated absorption (or Beer-Lambert absorption $N_2 B_{21} - N_1 C_{12} < 0$) dominates over stimulated emission process. That could been easily visualized in Fig.4

On the other hand, in a stimulated emission dominate regime $N_2 B_{21} - N_1 C_{12} > 0$, the neutrinos wave function maximum will be obtained at a later time than the time of flight of the light $t_1 = L/c$, that is $t_2 > t_1$ or Δt positive. So neutrinos will appear to be traveling much slower than light that they really are.

Let take the Beer-Lambert stimulated absorption case with $B_{21} = 0$. Then for approximately $N_1 \approx 10^{13}/vol$ with a tunnel volume $vol \approx 3000 m^3$ and for $\Gamma_o = 1/(\sigma_o^2)$ with $\sigma_o \simeq 3300ns$ taking into account the tunnel length and the duration of the pulse extraction $T = 10.5\mu s$ [1], we get for these "long" PDF pulses:

$$\Delta t = -\frac{N_1 C_{12} \sigma_o^2}{vol} \simeq 57.8ns \Longrightarrow C_{12} = \frac{\Delta t\ vol}{N_1 \sigma_o^2} \simeq 1.65 \times 10^{-6} \frac{m^3}{\text{sec}}$$

This will explain only partially the OPERA faster than light neutrinos, note that the result is energy independent consistent with the separated extractions result, day and night, etc. Because all the ~ 16000 events has the same mean width $\sigma_o \simeq 3300ns$ for long pulse CNGS operation. But the result is strongly dependent on σ_o. Then for the 20 short pulse events with $\sigma_o \simeq 3ns$ and $N_1 \approx 10^{12}/vol$ will give an insignificant time delay shift 10^{-7}shorter that for long PDF functions when calculating with the same C_{12} coefficient.

Then Beer-Lambert mechanism could explain only long PDF pulses, the reason is that for $3ns$ short pulse most of the decay tube length $L = 3300ns$ is empty, so the products $N_1\ n$ (either $N_2\ n$) in the Eq. (5) will be null almost every where. The solution (6) is not longer valid, then a complete analysis of equations (1),(2), and (3) taking into account the three processes stimulated emission, stimulated absorption and spontaneous decaying.

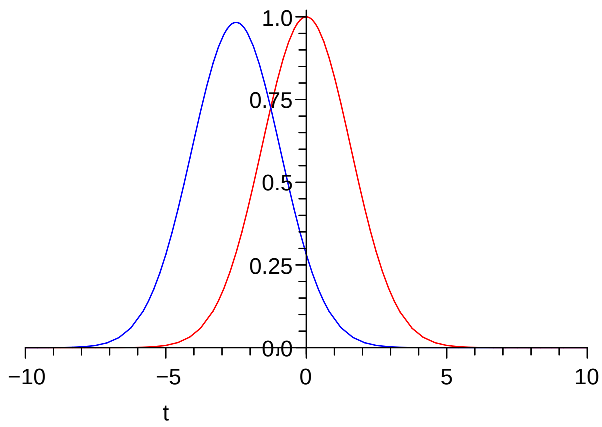

FIG. 4: Graphic vs time of the neutrino pulse at the end $x = L$ of the decay tunnel. Right, traveling at $\nu \approx c$. Left with stimulated absorption deformation of the wave packet showing early arrival $\Delta t < 0$.

V. CONCLUSIONS

As OPERA measurement depends on the fitting of the probability distribution function (PDF) of the meson (measured at the beginning of the tunnel) with a maximum likehood analysis of the neutrino peaks detected by OPERA, the results is strongly dependent if there is or not, a process of shape deformation of the wave intensity, as the proposed stimulated absorption of neutrinos. It was shown, there will be a forward in time shift due to the stimulated absorption of neutrinos. So the neutrinos seems to travel faster than light because this shifting had not been taking into account. So as said before, the neutrinos are starting its travel at different points, because its "creation" point is also traveling modulated by an amplification factor (6), as result the distance from its creation point to the detection point is continuously shortening.

For Gaussian pulses the maximum likehood analysis and the calculation with Eq.(13) leaving (14) are equivalent. This could easily be seen from the comparison of Eq.12 with a gaussian peak at the tunnel end $\xi = t - L/c = 0$ multiplied by an amplification factor (6) at $\eta = t + L/c$ by completing squares and eliminating normalization constants

$$\exp[-\frac{\Gamma_o}{2}(t - L/c)^2] \exp[(N_2 B_{21} - N_1 C_{12})\ (t + L/c)]| \propto \exp[-\frac{\Gamma_o}{2}((t - L/c)) - \Delta t)^2] \quad (15)$$

$$\Delta t = \frac{(N_2 B_{21} - N_1 C_{12})}{\Gamma_o}$$

Then a light like particle without amplification ($B_{21} = C_{12} = 0$) will achieve tunnel end at $\xi = t_1 - L/c$ as before, but if there is amplification, the best displaced gaussian fit to the original gaussian will be centered at $t_2 = t_1 + \frac{(N_2 B_{21} - N_1 C_{12})}{\Gamma_o}$ just like for Eq.(14).

With the knowledge of the density fluxes in the tunnel and the gaussian mean width of the pulses, it is possible to estimate the Einstein coefficients: in particular the stimulated neutrino absorption from in a Beer-Lambert approach ($B_{21} = 0 = A_{12}$)

$$C_{12} \simeq 1.6 \times 10^{-6} \frac{m^3}{\text{sec}}$$

Therefore long PDF pulses extraction ($T = 10.5\mu s$) could be explained without supposing that neutrino travel faster than light. The same calculation is not valid for short PDF pulses extraction because Eq.(5) is not longer correct in the approximation gradient of N_1 small.

There is a way to probe the existence of the stimulated neutrino emission: to compare the detected neutrino time distribution with the muon probability distribution function (PDF), instead of the meson PDF. Because the muon

and the neutrino are created at the same event, they must have the same forward time shift and there must be not difference in time at which intensities maximum are achieved.

In [1] the muon PDF was not considered, because the simulations show that will give null corrections. That is true if it is considers only spontaneous decay, note that $t_2 = t_1$ when $B_{12} = C_{21} = 0$. Muon PDF may be difficult to analyze because the muon is a very interactive charged particle, but comparison of muons PDF with detected neutrinos must be performed in order to establishes if neutrinos travel faster than light or stimulated absorption or emission of neutrinos exist.

As this work was been written it also has been argued that superluminal neutrino will decay very fast, by Cherenkov analogue [12] considering neutral current interactions, more recently reported that superluminal CNGS neutrinos do not decay as theoretically expected [13] pointing that OPERA neutrinos may be slower that light. To my point of view this objection to OPERA results is not valid because is based in a relativistic model, is the same as to said that Bohr atom is forbidden because of Larmor formula will make the electrons to radiate.

Acknowledgments

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